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ABSTRACT

This research studied the effects of computer-presented organizational/memory aids on problem solving behavior. The aids were either matrix or verbal charts shown on the display screen next to the problem. The 104 college student subjects were randomly assigned to one of the four conditions: type of chart (matrix or verbal chart) and use of charts (optional or required). Students did eight problems in each of two sessions--an initial task and a transfer task. All subjects used the charts in the initial task and most did so in the transfer task. Matrix charts were perceived to be more useful than verbal charts although group performance scores were not significantly different. The higher the score, the greater the probability that the chart was used. Performance scores on the transfer task improved significantly for students in optional conditions who were not at ceiling performance on the initial task. Subjects at different performance levels demonstrated knowledge of different strategies. (Author)

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Effect of Computer-Presented Organizational/Memory Aids on Problem Solving Behavior

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Effect of Computer-Presented Organizational/Memory Aids on Problem Solving Behavior

INTRODUCTION

Studies of novices' problem solving behavior and of instruction in problem solving, point to several reasons why instruction is often unsuccessful. Students bring with them their own spontaneous problem solving strategies. They are frequently unwilling to reject their own strategies in favor of the ones presented by the instructor even though their own are inadequate (Fuller, 1982).

People have different preferred problem solving styles. For example, some are perceptive, others receptive (McKenney and Keen, 1974); some impulsive, others reflective (Zelnicker and Jeffrey, 1976). If there is a mismatch between the problem solving style being presented and that of the problem solver, the instruction may not be fully understood, or even accepted by the novice. Novices are impatient to get started on the problem solving process and frequently do not take the time to formulate plans or to generate and evaluate alternative plans.

Intuitively reasonable techniques for problem solving instruction have also been shown to be inadequate. For example, sequencing the order of problems from easy to hard is not effective if students can solve easy problems by special strategies that are not applicable to harder problems (Steinberg, 1983). Similarly problem solving by analogy sometimes fails because students fail to recognize the limitations of the analogy (Burstein, 1983).

Based on the above observations, it seems reasonable to hypothesize that instruction in problem solving is more likely to be successful if it begins with an understanding of students' spontaneous behavior and provides tools to help them improve their problem solving strategies.

In the present research, a problem called Pico-fomi is the vehicle for studying problem solving behavior; an organizational/memory chart is the tool provided to improve or facilitate problem solving skills. The problem and the chart will be explained next and will be followed by a discussion of the rationale for choosing these instruments.

THE PICO-FOMI PROBLEM

In the Pico-fomi problem, the computer randomly generates a 4-digit number, using the digits from 1 to 8, but does not show the target number to the problem solver.

The objective is to figure out the number in as few trials as possible. The problem solver chooses a number and the computer gives feedback about how many digits are correct and in the correct position and how many are correct but in the wrong position.

The problem solver's first response can only be a guess, but subsequent ones can be built on inferences from previous responses and related feedback. Suppose, for example, that the target number is 3487 and that the problem solver's first guess is 4251. The feedback from the computer is that one of the digits is correct but not in the correct position (i.e. not in the same position as in the target number). Inexperienced problem solvers frequently conclude that "nothing" is learned from this partial information, but good problem solvers are aware that useful information can be deduced. Although they do not know which digit is correct, they can infer that whichever digit it is, it will not be in the same position in the target number as it is in the guess. For example, whether the digit 1 is in the target number or not it will not be in the right-most place. Similarly, 2 will not be in the middle left, nor 4 in the left, nor 5 in the middle right position.

An even more subtle inference can be made and recorded in the following instance. Suppose the problem solver's next guess is 3615, the computer's feedback is that one of the digits is correct and in the correct position. Again, there is no way of inferring complete information, that is which digit is the correct one. However, it is possible to infer which positions each digit can not occupy in the target number. If 5, for example, must be in the right most position, it cannot be in any of the other three.

CHARACTERISTICS OF PICO-FOMI PROBLEMS

The Pico-fomi problem belongs to the wide-ranging domain of problems in which (1) there is a large but finite number of possible solutions, (2) the problem solver is given only minimal information initially, and (3) there does not exist a prespecified set of solution rules. Medical diagnosis and finding a faulty component in an electrical circuit share these properties.

Pico-fomi was chosen because it is context free. Since solving the problem does not depend on a specific body of subject matter knowledge, it is possible to study learners' problem solving strategies without the confounding effects of their knowledge of the subject matter.

Two strategies are particularly appropriate for efficiently solving problems in this domain. One strategy

is to decrease the number of possible solutions as efficiently as possible; another is to make inferences from partial information, both positive and negative. In the process of applying these strategies a person generates a tremendous number of inferences, often too many to hold in short term memory. Yet the problem solver must be able to access this information readily in order to make further deductions and to decide how to proceed in the problem solving process. Tools that serve as external memory and organizational aids should reduce the memory load, enabling the problem solver to devote full attention to generating problem solving strategies. These aids are likely to be most useful if they enable the problem solver to record all of the inferred information, partial as well as complete. Charts can serve as such aids.

CHARTS

The two types of charts used in this study were a verbal chart and a matrix chart. The verbal chart was designed to summarize the results of inferences in a narrative fashion. The matrix chart was a more detailed tabular representation for all possible individual inferences. The matrix chart was designed to appeal more to problem solvers with an analytical approach to solving problems and the verbal chart to problem solvers with a less analytical approach.

The charts used in this experiment are structured so that both their organization and content is useful for the problem solver. The verbal chart divides the inferences into several broad categories and allows the subject to record information in each category. The matrix chart has the four digit positons across the top and the possible digits down the side. Thus, there is a cell for each digit in each position (1-4). The subject can mark that a given digit is known to be in a given position, known not to be in a given position, and in some position which is not known.

The verbal chart requires the summarizing of results of testing before a subject can record inferences. The matrix chart allows the vast majority of inferences possible to be recorded. Examples of the charts can be found in Figures 1 and 2.

RESEARCH QUESTIONS

The following questions were addressed to determine the effect of making such aids available to problem solvers:

(1) If a chart is available and use is optional, will novice problem solvers use it?
(2) How does use of chart relate to problem solving performance?

(3) If problem solvers are forced to use the chart initially, will they continue to use it when no longer required to do so?
(4) How does the requirement to use the chart affect performance?
(5) If use of the chart is accompanied by improved performance, can improvement be ascribed to the matrix format of the chart or to the presence of an organizational tool per se?

METHCD

Design.

Two chart formats were designed, matrix (Figure 1) and verbal (Figure 2). Two response requirements were also devised. The student had the option of using the chart at will, or else was forced to record all inferences. Four experimental conditions were generated from all possible combinations of response requirement and type of chart.

Subjects participated in two sessions, one week apart. In the initial session a chart was always present on the display, and the option or the requirement to use it depended on the subject's randomly assigned condition. In the second session the chart was not automatically presented, but all subjects had the option of asking for it and of using it.

Independent variables were the response requirement (optional or forced), the type of chart (verbal or matrix), and the task (initial or transfer). Dependent variables were the number of problems solved, time to solve them, number of times the chart was used overall, number of students requesting the chart in transfer task, and proportion of students who learned specific strategies.

Subjects.

Subjects were 104 paid college students who responded to an advertisement. They were paid $10 each.

Materials.

The task was the 4-digit Pico-fomi problem. The instructional vehicle was PLATO, the University of Illinois system for computer-assisted instruction.

Procedure.

Subjects were randomly assigned to one of the four experimental conditions. Except for a printed sheet of instructions for how to get started on the computer, the presentation, directions as well as problems, was conducted on the computer terminal.

The computer monitored each student's problem solving process and for every step of every problem kept a record of each deductive rule that could be applied and whether the subject did apply it, as evidenced by marking the inference on the chart.

Initial task. Students in forced conditions were told what additional deductions could be made if they had omitted some, and were required to record them on the chart before going on the the next step in the problem. In optional conditions subjects were urged to use the chart but were neither forced to do so nor told when their use was incomplete.

Rules for the Pico-fomi task were presented first, followed by a practice problem. The appropriate chart and directions for using it were next. This was followed by eight randomly generated problems. Students were allowed a maximum of 8 trials to solve each one. If the subject did not succeed within 8 trials, the computer displayed the target number. The entire task was self-paced.

Transfer task. After a summary of rules of Pico-fomi, subjects were told that they could request a chart at any time. Eight randomly generated problems were presented.

RESULTS

Scores. Subjects in forced conditions scored (Table 1) significantly higher than those in optional in the initial but not in the transfer task. Task, response requirement and interaction of the two are all significant, $F(1,200) = 3.99$, $p < .05$, $F(1,200) = 11.08$, and $F(1,200) = 23.28$, $p < .001$, respectively (Table 2).

Since a score of 7 or 8 correct out of 8 possible is at or near ceiling, there is little or no room for improvement. Scores were calculated separately for subjects in optional conditions who were and who were not at ceiling initially (Table 3). Subjects who scored less than 7 initially improved on the transfer task. Initial score was a significant effect, $F(1,96)=59.18$, $p < .001$ (Table 4). Interaction of initial score by task was also significant, $F(1,96)=4.23$, $p < .05$.

Time. Matrix charts required more time than verbal, initial task more time than transfer, and forced more time than optional conditions (Table 5). All are significant main effects, $F(1,200) = 13.49$, $p < .001$; $F(1,200) = 29.46$, $p < .001$; and $F(1,200) = 16.71$, $p < .001$, respectively (Table 6). Also significant are interactions of aid by task, $F(1,200) = 3.89$, $p < .05$ and triple interaction of aid

by task by response requirement, $F(1,200) = 4.05$, $p < .05$.

Grouping subjects by initial scores in optional conditions (Table 3), aid, task, and initial score are all significant main effects, $F(1, 96) = 3064.44$, $p < .001$; $F(1, 96) = 301.99$, $p < .001$; and $F(1, 96) = 1122.06$, $p < .001$, respectively (Table 4). All interactions are also significant: aid by task, aid by initial score, task by initial score, and aid by task by initial score $F(1, 96) = 135.42$, $p < .001$; $F(1,96) = 372.52$, $p < .001$; $F(1, 96) = 8.73$, $p < .01$; and $F(1, 96) = 55.95$, $p < .001$, respectively. Matrix conditions required more time than verbal in both initial and transfer tasks, and initial task required more time than transfer task. Subjects who scored at or near ceiling in the initial task took more time per problem than those whose scores were below ceiling. This pattern of more time for the higher scores remained about the same on the transfer task for matrix condition, but decreased for verbal. The time difference between verbal and matrix conditions was greater for subjects who scored 7 or 8 than those who scored below 7.

Use of charts. In the initial task, every subject, in optional as well as forced conditions, used the chart. Subjects in optional matrix chart condition whose scores were less than 4 touched charts 2/3 as often as average (score 5 or 6) and high (score 7 or 8) performers; for verbal charts there were no differences in chart use by performance level (Table 7). Verbal charts held much less detailed information than matrix, so as expected, the number of touches is much lower. For both matrix and verbal charts, subjects in optional conditions used charts a little more than one third as frequently as those in forced conditions.

In the transfer task, the proportion of subjects who asked for charts was approximately the same for all conditions, about 76% (Table 8). Collapsing across type of chart and response requirement, the proportion who asked for charts increased as the performance level increased. The better the performer, the greater the probability of asking for charts.

Subjects were asked on a post-experiment questionnaire whether they found the charts useful. The response patterns were different in matrix and verbal conditions. In matrix conditions, perceived usefulness of the chart varied directly with the score: the higher the score, the greater the proportion of subjects who found the chart useful. For verbal charts, most subjects who scored 7 or 8 perceived the chart to be useful but just the reverse was true of subjects who scored 5 or 6. Those who scored below 5 were evenly

divided in their perception of the usefulness of the chart.

Strategy learning (matrix conditions). Inferences from rules A and C (Appendix A) can be marked directly on the chart. Most students did so spontaneously or learned to do so with practice.

Overall, subjects in matrix optional conditions marked inferences from Rule A with 41% frequency in the initial task and 62% on transfer; in forced condition, with 75% and 77% frequency in initial and transfer tasks, respectively (Table 9). In optional condition Rule C was marked with 75% and 63% frequency in initial and transfer conditions, respectively; the comparable figures were 93% and 74%, respectively for forced condition.

In contrast, Rule B, which requires a chain of inferences, was applied with 17% and 22% frequency in initial and transfer tasks, respectively, in optional condition and 47% and 24% respectively in forced condition. Subjects in matrix condition who scored less than 5 applied Rule B with 14% frequency compared to 29% and 26% for average and good scores, respectively. Similarly in matrix conditions the frequency of marking Rule E increased as score increased, from 21% to 42% to 53% in the transfer task for low, average, and good scores, respectively.

DISCUSSION

Mean score improved significantly for students in optional conditions who were not initially at or near ceiling.

Charts facilitated problem solving performance. All of the subjects in optional, as well as forced conditions, used the chart in the initial task. Most subjects also used charts on the transfer task. The better the score, the greater the probability that the chart was used.

Matrix charts were more useful than verbal charts. Although scores were no higher for matrix than verbal conditions, average and high performers in optional conditions maintained the same frequency of use of matrix charts in the transfer task. In contrast, use of verbal charts decreased from initial to transfer task.

In addition, a substantially bigger proportion of subjects in matrix than in verbal conditions thought the chart was helpful. Much of the detailed information that can be recorded on matrix charts must be summarized before it can be recorded on verbal charts. Therefore it is not

surprising that actual use of charts in transfer conditions decreased with decreasing scores in verbal, but not in matrix conditions.

The value of the charts was different for subjects at different cognitive entry levels. The higher the score on transfer task, the greater the probability that the subject requested a chart and the more likely the subject was to think that the chart was useful. In addition, performers at different cognitive levels learned different rules in forced matrix conditions. The poorest performers learned the simplest deductive rules. Highest performers were more likely to apply two of the complex rules involving more than one guess and more than one step in the reasoning chain. Good performers used the chart for the purpose for which it was valuable: access to details in application of a complex rule.

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TABLE 1

Mean Number of Problems Solved

	Initial Task					
	Optional			Forced		
Aid	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Matrix	26	5.538	1.726	26	7.308	1.087
Verbal	26	5.346	1.695	26	7.346	.846
	Transfer task					
Matrix	26	6.269	1.823	26	5.846	1.826
Verbal	26	5.923	1.809	26	5.654	2.134

TABLE 2

Analysis of Variance of Number of Problems Solved
By Chart Type, Task, and Response Requirement

Source	df	MS	F
Main Effect			
Aid (A)	1	1.5563	.56
Task (T)	1	11.0751	3.99*
Response requirement (RR)	1	30.7908	11.08***
Interaction			
A x T	1	.4792	.17
A x RR	1	.4792	.17
T x RR	1	64.7057	23.28***
A x T x RR	1	.0188	.01
Within cells	200	2.7792	

* $p < .05$
** $p < .01$
*** $p < .001$

TABLE 3

Performance in Optional Conditions, Grouped by Initial Score

	Initial task, mean scores					
	Score 7 or 8			Score $\leq$ 6		
Aid	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Matrix	8	7.625	.518	18	4.611	1.145
Verbal	8	7.250	.463	18	4.500	1.295
	Transfer task, mean scores					
Matrix	8	7.750	.463	18	5.611	1.819
Verbal	8	6.750	1.832	18	5.556	1.723
	Initial task, total time in seconds					
	Score 7 or 8			Score $\leq$ 6		
Aid	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Matrix	8	3383.	69	18	2634	82
Verbal	8	2401.	47	18	2070	79
	Transfer task, total time in seconds					
Matrix	8	3466	174	18	2348	74
Verbal	8	1808	73	18	1637	56

TABLE 4

Analyses of Variance of Performance in Optional Conditions,

Grouped by Initial Score

	Number Solved			Total Time		
Source	df	MS	F	df	MS	F
Main effect						
Aid (A)	1	3.2880	1.70	1	21222312	3064.44***
Task (T)	1	3.9126	2.02	1	2091380	301.99***
Initial Score (IS)	1	114.5844	59.18***	1	7770684	1122.06***
Interaction						
A x T	1	.4483	.23	1	937840	135.42***
A x IS	1	2.0239	1.05	1	2579850	372.52***
T x IS	1	8.1827	4.23*	1	60481	8.73**
A x T x IS	1	.6421	.33	1	387472	55.95***
Within cell	96	1.9363		96	6925	

* $p < .05$
** $p < .01$
*** $p < .001$

TABLE 5

Total Time in Seconds

	Initial task					
	Optional			Forced		
Aid	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Matrix	26	2865	845	26	3591	832
Verbal	26	2172	710	26	2872	1125
	Transfer task					
Matrix	26	2393	785	26	2212	809
Verbal	26	1690	607	26	2490	1300

TABLE 6

Analysis of Variance of Total Time
By Chart Type, Task, and Response Requirement

Source	df	MS	F
Main effect			
Aid (A)	1	10967349	13.49***
Task (T)	1	23956481	29.46***
Response requirement (RR)	1	13591581	16.71***
Interaction			
A x T	1	3166049	3.89*
A x RR	1	2964081	3.65
T x RR	1	2116559	2.60
A x T x RR	1	3295659	4.05*
Within cells	200	813141	

* $p < .05$
*** $p < .001$

TABLE 7

Number of Touches on Initial Task, Grouped by Score

Condition	Score 7 or 8			Score 5 or 6			Score < 4		
	N	$\bar{x}$	SD	N	$\bar{x}$	SD	N	$\bar{x}$	SD
Optional									
Matrix	8	142.5	58.525	8	147.5	66.905	10	108.5	74.551
Verbal	8	35.75	22.764	11	31.091	20.739	7	31.000	17.635
Forced									
Matrix	21	366.571	91.187	5	324.2	83.532	0		
Verbal	25	94.680	46.596	0			1	20.0	0.0

TABLE 8

Number of Subjects Who Requested Charts on Transfer Task

Condition	Requested	Did Not
Matrix		
Optional	21	5
Forced	19	7
Verbal		
Optional	18	8
Forced	21	5
	All Conditions	
Score $\leq$ 4	17	10
Score 5 or 6	24	8
Score 7 or 8	38	9

TABLE 9

Average Frequency of Occurrence of Rules Per Person Who Used Chart and Percent of Applications, by Score and Task in Matrix Conditions

Condition	Overall				Score ≤ 4 (Poor)				Score 5 or 6 (Ave)				Score 7 or 8 (Good)			
	Initial		Transfer		Initial		Transfer		Initial		Transfer		Initial		Transfer	
	(N)	Freq	(N)	Freq	(N)	Freq	(N)	Freq	(N)	Freq	(N)	Freq	(N)	Freq	(N)	Freq
RULE A																
Optional	(26)	19 41	(21)	16 62	(10)	20 31	(5)	19 42	(8)	19 54	(5)	15 78	(8)	17 42	(11)	15 67
Forced	(26)	15 75	(19)	16 77	(1)	-- --	(4)	14 73	(5)	18 91	(7)	20 79	(21)	14 70	(8)	15 76
RULE B																
Optional		11 17		6 22		13 12		6 13		11 19		7 34		9 24		6 20
Forced		7 47		8 24		-- --		9 14		7 42		10 29		7 48		5 26
RULE C																
Optional		5 75		3 63		6 69		5 74		5 89		3 64		4 71		3 55
Forced		5 93		5 74		-- --		3 20		4 95		6 81		6 92		5 79
RULE E																
Optional		21 39		16 42		25 32		19 39		21 47		17 49		16 42		14 40
Forced		15 67		16 41		-- --		16 21		19 69		20 42		14 66		13 53

Problem number 1

PLATO is thinking of a 4 digit number.

Digits to pick from:

1	2	3	4	5	6	7	8

Your guess ❯

position

	L	ML	MR	R
1				
2				
3				
4				
5				
6				
7				
8				

★ one right digit, right place.
☆ one right digit, wrong place.
ZILCH no correct digits.

FIGURE 1

Problem number 1

PLATO is thinking of a 4 digit number.

Digits to pick from:

1	2	3	4	5	6	7	8

Your guess ❯

Digits correct and placed

____ ____ ____ ____

Digits in, but not placed

____ ____ ____ ____

Digits not in the number

____ ____ ____ ____

Digits considered but not established to be in or out

__ __ __ __ __ __ __

★ means one right digit in right place.
☆ means one right digit in wrong place.
ZILCH no correct digits.

E.

20

FIGURE 2

APPENDIX A

LIST OF RULES

A) If all stars in feedback are open stars:

The digit cannot be in current position; mark it not in this position.

B) If all stars in feedback are closed stars:

If digit is in, it must be in current position; mark other positions as out.

C) If there are four stars in the feedback:

All of the digits in the guess are in; mark them in. Mark other digits out.

E) If feedback has gained (or lost) the same number of stars as the number of digits replaced in the guess:

The new digits are in (out) and the digits that were replaced are out (in); mark them accordingly.